Section II-4

technology program

The next generation of spacecraft that will carry out our broad program of exploration must be more capable and more reliable while being more efficient in mass and power consumption. Some systems (telescopes, for example) will be much larger than today's; others (in situ probes for space physics, for example) will be much smaller. During the preparation of this Strategic Plan, the roadmap teams in the major Enterprise science areas that formulated science goals and collected and assessed mission concepts also analyzed the technical capabilities that would be needed to implement these concepts. These Enterprise technology needs were aggregated into ten *key capability* areas.

Key Capabilities

Advanced power and on-board propulsion are needed to support more capable instrumentation and telemetry, as well as to enable spacecraft to travel deeper and faster into space. Development in these areas will focus on power generation (solar and nuclear) and energy storage (battery technologies and flywheels); chemical, ion propulsion, and attitude control systems; solar sails; and micropropulsion systems and components.

Sensor and instrument component technology progress is needed to provide new observational capabilities for astrophysics, space physics, and planetary science remote sensing, as well as vehicle health awareness. Areas for future work include miniaturized in situ and advanced remote sensing instruments, and new sensing techniques using distributed spacecraft and bio-sensors for astrobiology. Of particular importance to space science is instrument capability to perform in harsh environments: vacuum, extreme temperatures, and intense radiation fields. New detector technologies will be based on fundamentally new measurement principles and techniques using new materials and architectures, as well as expanded use of different spectral regions.

Of particular importance to space science is instrument capability to perform in harsh environments: vacuum, extreme temperatures, and intense radiation fields.

Many future mission concepts require constellations of platforms that act as a single mission spacecraft for coordinated observations or in situ measurements, or act as a single virtual instrument (for example, interferometry or distributed optical systems). Major areas for work in **distributed spacecraft control** are: advanced autonomous guidance, navigation, and control architectures; formation initialization and maintenance; fault detection and recovery; and intersatellite communications.

High rate data delivery is essential to support virtual presence throughout the Solar System. We also want to minimize the mass and resource requirements of communications subsystems. Topics for advanced development in high rate data delivery include: information extraction and compression; low-cost, low-mass systems; optical communications; in situ communications for surface exploration; improved components for deep space communications; and high rate distributed information systems.

Very advanced space systems will be self-reliant, self-commanding, and even inquisitive. These **intelligent space systems** must be able to: plan and conduct measurements based on current or historical observations or inputs; recognize phenomena of interest and concentrate activities accordingly; and monitor and maintain desired status or configuration over long periods of time without frequent communication with ground.

Many science objectives benefit from more populous spacecraft constellations or more frequent flight opportunities at a fixed cost. The former category includes constellations of measurement platforms in flight as well as networks of landed spacecraft for in situ measurements. These **micro- or nano-sciencecraft** would have: smaller, more lightweight, more capable and resource-efficient spacecraft "bus" and "payload" components; efficiently integrated bus-payload spacecraft designs; high performance data compression technology; low power, high performance electronics; and micro-electromechanical systems (MEMS) technology.

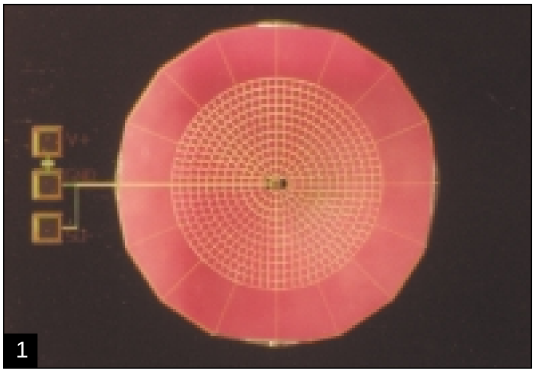
Very advanced space systems will be self-reliant, self-commanding, and even inquisitive.

Advances in exploration of planetary surfaces will depend on **surface systems** technologies for safe, self-sufficient, and self-sustaining robotic and human presence independent from Earth for indefinite periods of time. Basic technology elements needed for surface and sub-surface sampling of planetary surfaces and small bodies will be teleoperated, along with autonomous robots and rovers with increased intelligence, speed, maneuverability, and dexterity. Specific capabilities would include drills, coring devices, and scoops, as well as sample handling, packaging, and return mechanisms.

Very large (km-scale) non-precision structures in space (e.g., sunshields, sails) and large (100m) precision structures (e.g., optical reflectors, antennas) levy new requirements for **ultra-lightweight space structures and observatories**. Progress is needed in: materials; inflatable and deployable structures, including control for precision deployment and maintenance; lightweight optics and optical structures, and thin-film materials; and radiation shielding, survivable spacecraft materials, and telescope technology.

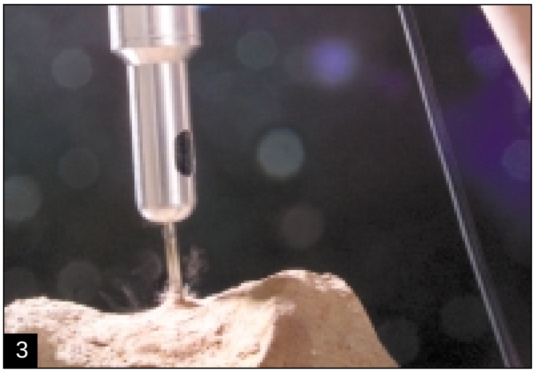
Improved reliability and agility are needed for in-space docking and flight in planetary atmospheres. **Atmospheric systems and in-space operations** development will focus on aero-maneuvering (ascent, entry, and descent systems, and aero-shell and hazard avoidance systems), aerial systems (balloons, airplanes, rotorcrafts, and gliders), and operations (rendezvous, docking, and sample transfer systems).

To bring all of these advanced flight capabilities together in innovative mission designs, we will need a **next generation infrastructure** on the ground. This will include high performance computing and networking, support for collaborative work, advanced design tools, and distributed networks of computer resources. Tools will be developed to increase efficiency and speed of technology maturation and infusion.

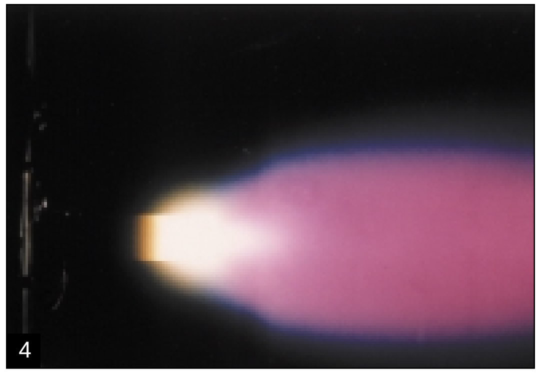


1

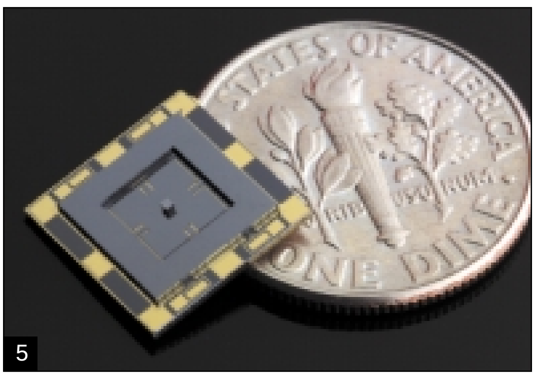
2



3



4



5

6

1. The Boomerang micromesh bolometer, reminiscent of a spider's web, uses a free-standing micromachined mesh of silicon nitride to absorb millimeter-wave radiation from the cosmic microwave background. Millimeter-wave radiation is absorbed and measured as a minute temperature rise in the mesh by a tiny Germanium thermistor, cooled to three tenths of a degree above absolute zero. **2.** Aerogel, a low density material made from silicon dioxide, is protecting some crayons from the heat of the flame. Aerogels have primarily been used in scientific applications, most commonly as a particle detector in high energy physics. **3.** An ultrasonic driller/corer developed at NASA Jet Propulsion Laboratory is shown drilling sandstone while being held from its power cord. Relatively small vertical force is used in this application—a factor that will be useful when the drill is used in future space missions to drill and core for samples during planetary and asteroid explorations. **4.** A high power plasma thruster operates at a current level of 20,000 amperes and a peak power level of 10 megawatts. The technology may eventually be used to propel cargo or piloted vehicles to Mars and beyond. **5.** This new microgyroscope is lighter, cheaper, higher-performing, and less complex than its conventional counterparts while uniquely designed for continuous space operation. Its dimensions are 4 by 4 millimeters, smaller than a dime, and its weight is less than one gram. **6.** The Goldstone Deep Space Communications Complex, located in the Mojave Desert in California, provides radio communications for all of NASA's interplanetary spacecraft and is also utilized for radio astronomy and radar observations of the Solar System and the universe.

Key Enabling Technology Capabilities	Mission Lines								
	Origins Observatories	Solar Terrestrial Probes	Mars Surveyor	Outer Planets	Living with a Star	Cosmic Journeys	To Build a Planet	Astrobiology Initiative	Interstellar Probe
Advanced Power and On-Board Propulsion			■	■	■	■	■		■
Sensor and Instrument Component Technology	■	■	■	■	■	■	■	■	
Distributed Spacecraft Control	■	■			■	■			
High Rate Data Delivery		■	■	■	■		■		■
Intelligent Space System			■	■			■	■	■
Micro-/Nano-Sciencecraft		■	■	■	■		■	■	■
Surface Systems			■	■			■	■	
Ultra-Lightweight Space Structures and Observatories	■			■	■	■			■
Atmospheric Systems & In-Space Operations			■				■		
Next Generation Infrastructure	■	■	■	■	■	■	■	■	■

Space Science Technology Programs and Technology Readiness Levels

TRL 1 Basic principles observed and reported

TRL 2 Technology concept and/or application formulated

TRL 3 Analytical and experimental critical function and/or characteristic proof-of-concept

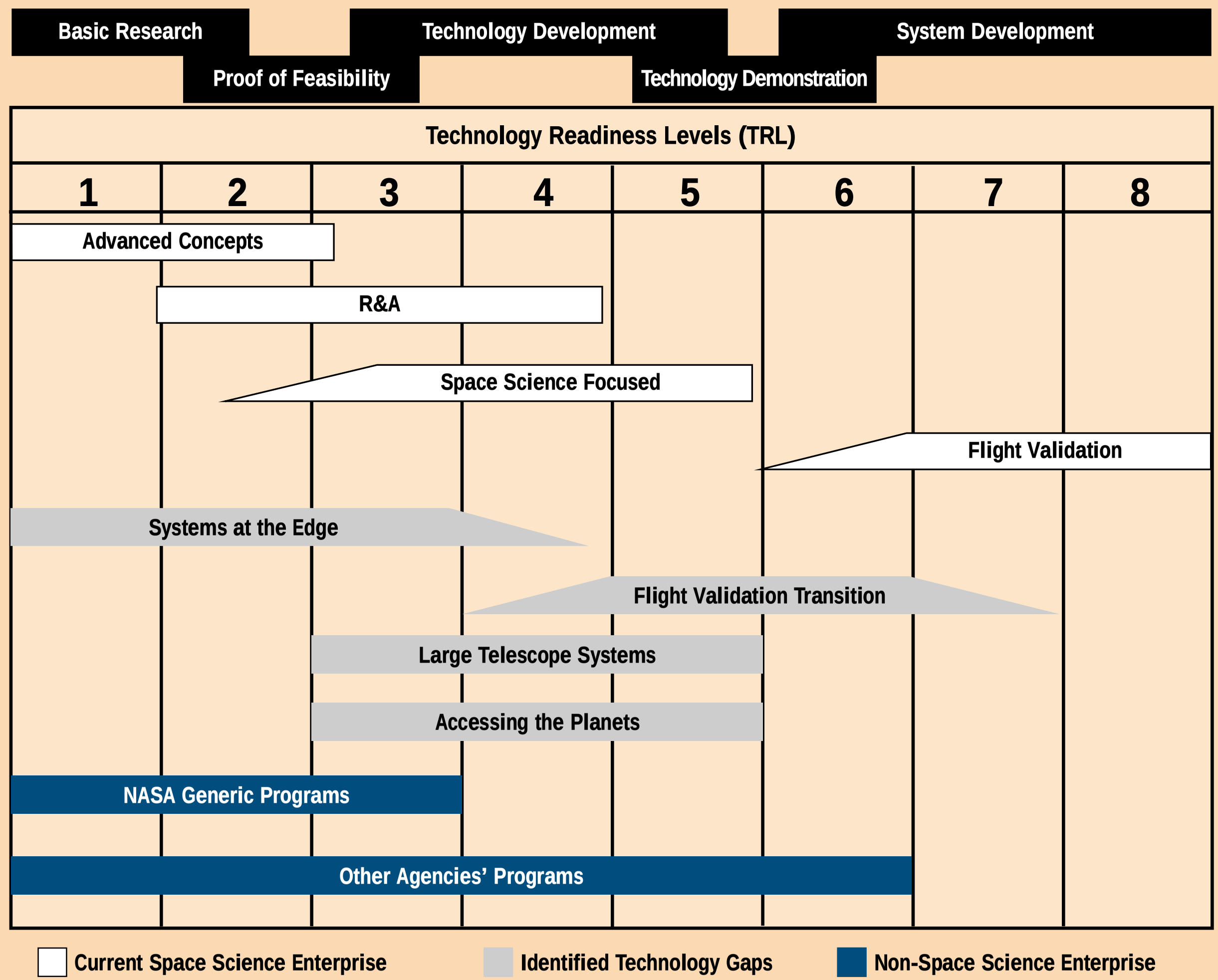
TRL 4 Component and/or breadboard validation in laboratory environment

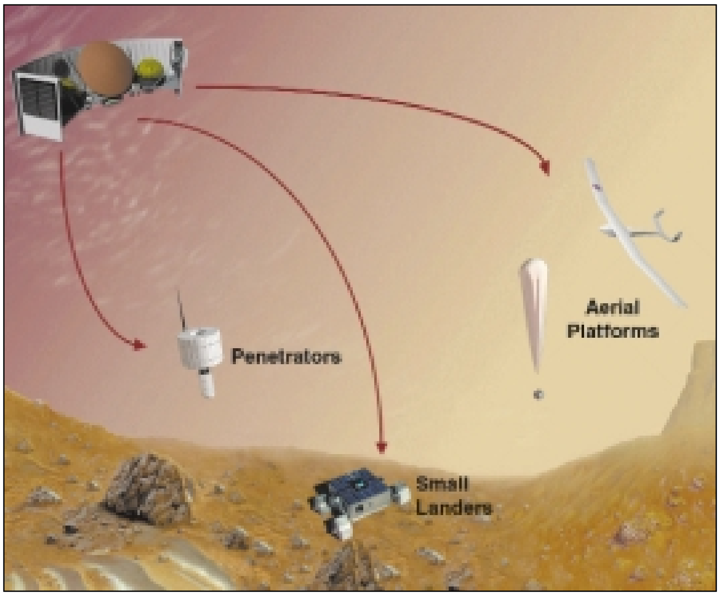
TRL 5 Component and/or breadboard validation in relevant environment

TRL 6 System/subsystem model or prototype demonstration in a relevant environment (ground or space)

TRL 7 System prototype demonstration in a space environment

TRL 8 Actual system completed and "flight-qualified" through test and demonstration (ground or space)





A broad range of new technologies will be needed to carry out future space science missions. For planetary exploration, these include communications, instrumentation, descent systems, and intelligent mobile platforms.

The Technology Life Cycle

Taken with the Agency's Cross-Enterprise Technology Program that focuses on early stage technology research, Enterprise technology programs span the full spectrum of technology maturity, from fundamental seed ideas through flight validation. The concept of Technology Readiness Levels (TRLs) provides a systematic approach to technology management that supports maturity assessment and a consistent comparison of maturity between different types of technology. Technology products typically progress through the development cycle through multiple programs. For instance, after an advanced proof-of-concept is demonstrated, it may be transitioned into either the Enterprise focused program or into the cross-Enterprise program for continued development, depending on the breadth of its applicability. This would be followed by system-level development and flight validation in the focused or flight validation programs.

Enterprise Technology Program Components

The Space Science Enterprise technology program to advance the state-of-the-art in the ten focus areas is organized into three major elements: an advanced concepts program, a focused technology program, and the New Millennium flight validation program.

The **Advanced Concepts Program** conducts studies for far-term technology (10-25 years in the future) by eliciting long-range science ideas, developing relevant far-term system concepts, and then deriving technology requirements and innovative approaches to support them.

The **Focused Technology Program** addresses high-priority technology requirements that directly support missions in the Enterprise Strategic Plan. While activities within this program are driven by the needs of space science, other Enterprises often benefit from them.

The **New Millennium Program** completes the technology development life cycle by validating new technologies in space. In addition to dedicated technology missions, other flight validation platforms, including the Space Shuttle and International Space Station, balloons, sounding rockets, and piggyback spacecraft or launch vehicle opportunities are also used to validate technologies in the space environment. Demonstrations flown as secondary payloads on expendable launch vehicles flown by NASA, or co-manifested on other U.S. Government or commercial concerns' launches, offer still other opportunities. The possibility of cooperation within international partnerships for technology demonstration is also being explored.

In addition to these major Enterprise technology programs, the Enterprise provides requirements to, and benefits from, **Agencywide technology programs**: Cross-Enterprise Technology Development Program (CETDP), High Performance Computing Capability (HPCC), and NASA Institute for Advanced Concepts (NIAC). These programs support technology requirements for all NASA space Enterprises, focusing on early stages of the technology life cycle for multiple Enterprise users. They emphasize basic research into physical principles, formulation of applications concepts, and component-level performance evaluation.

The program analyses performed in conjunction with the preparation of this Plan have revealed gaps in the capability to meet the technology needs of the Space Science Enterprise and its future expansion. We are therefore taking steps to fill these gaps by proposing a **new technology initiative** that encompasses several programs. These include Systems at the Edge (focusing on low TRL research), Accessing the Planets (for in situ planetary exploration), Flight Validation Transition (promoting transition of new technologies to space demonstration), and a Large Space Telescope Initiative (for far-term space observatories).

In addition to these major Enterprise technology programs, the Enterprise provides requirements to, and benefits from, Agencywide technology programs.

Technology Management

Management of the technology life cycle for **strategic, NASA-formulated missions** begins with the science theme roadmaps described in Section II-1. The Enterprise allocates resources in the Focused Technology Program and establishes priorities for the New Millennium Program and the Cross-Enterprise Program. The Research and Analysis program's yearly research solicitation also reflects the priorities established by the Science Board of Directors.

The technology programs are reviewed quarterly by Enterprise management. A Technology Steering Group, staffed by key program technologists at the NASA Centers, analyzes on a continuing basis the efficiency of resource allocations (gaps, overlaps, and redundancies) in the technology programs. The Steering Group reports periodically to Enterprise management. The Steering Group uses a variety of system analysis, risk analysis, and investment analysis tools and processes to determine the relative benefits and costs of alternative technologies, both those developed internally and those provided by university and industry partners.

Selected technology programs are periodically peer reviewed by external expert technologists on behalf of Center and Headquarters management. On the basis of these reviews and reports, reallocation of resources is considered by the Enterprise every year during the budget development process or whenever appropriate in response to deviations from planned performance or budgets.

Technology infusion into the **community-formulated Explorer and Discovery programs** occurs by a different path, since these missions are proposed as integrated packages by the research community and proceed directly to detailed definition without the benefit of a lead-in technology development program. For the Explorer program, an annual research solicitation offers a technology funding opportunity, primarily for instrument development. The Research and Analysis program offers a competitive program for funding of instrument development for planetary exploration. The selecting official has the option to allocate a small amount of funding for a proposal of unusual scientific merit that is not selectable because it is considered technically immature. Up-to-date information on technologies considered ready to fly is provided to proposers in the Explorer and Discovery programs, as well as to the proposal reviewers to ensure that a consistent standard for technical readiness is applied during the review process. Finally, technology developments supported under the Focused Technology Program for the NASA-formulated missions also become available to community proposers in the Explorer and Discovery programs.